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Chopper Stopper Thermal Considerations

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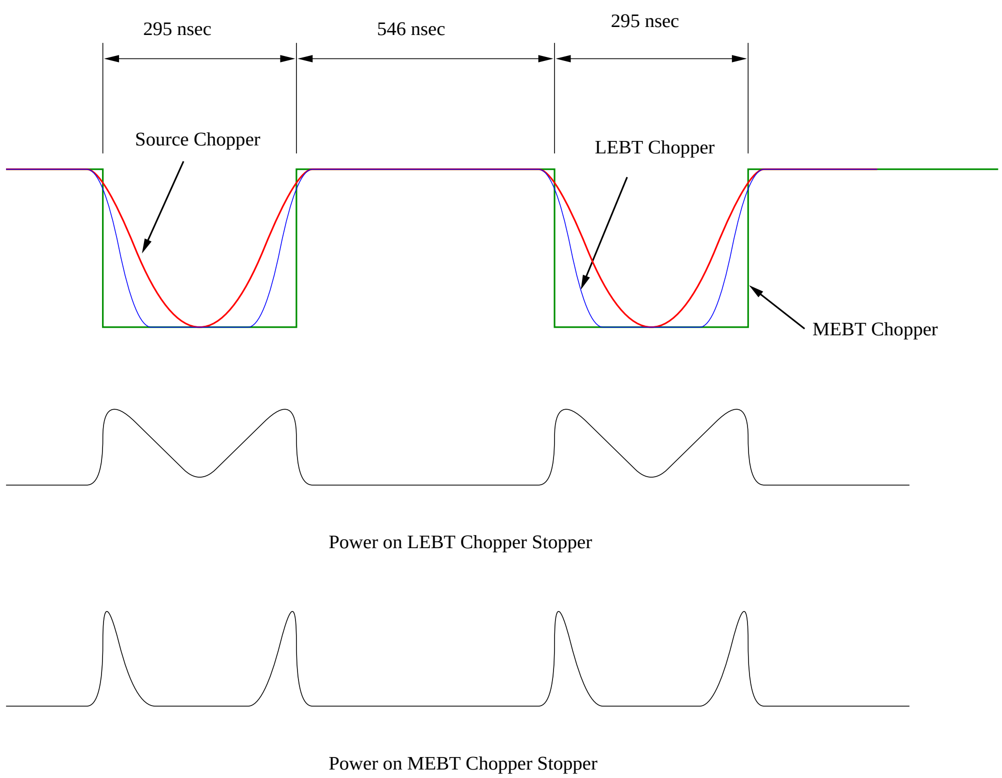
Beam chopping is carried out at three places in the front end: in the source, in the LEBT and in the MEBT. The fundamental chopping frequency is about 1.2 MHz, with a gap of 295 nsec placed in the 1 millisecond-long pulse. The repetition rate of the one millisecond pulses is 60 Hz, and with 28 mA peak intensity during the pulse, the average power delivered to the linac is 2.5 MeV$\times$ 28 mA$\times$ 6% duty factor$\times$ 65% beam-on time = 2.7 kW. The power dissipated on each chopper aperture depends on the beam energy at that point and the fraction of beam that survives to that point during the "notch" part of the beam waveform.

The beam will first be chopped at the ion source by manipulating the plasma, and is expected to have approximately a 100 nsec rise and fall time. It is not expected that the beam current will be reduced to zero during this phase of chopping. The second chopper will be located at the end of the LEBT, where the transition time is expected to be 35-50 nsec, and the beam transmission will be nearly zero in the central part of the "notch". The final chop takes place in the MEBT with an expected transition time of less than 5 nsec.

Beam power will be dissipated on the second (LEBT) and third (MEBT) "chopper stoppers". The following figure shows the chopper waveforms and the power dissipated on the LEBT and MEBT chopper stoppers.



The power on the LEBT chopper stopper reflects the decrease, in the middle of the pulse, of the current due to chopping in the ion source itself. Similarly, the power on the MEBT chopper stopper reflects the fact that most of the beam has been eliminated upstream except at the fast-transition edges.

The average power on the LEBT chopper stopper will be less than 50 watts at 65 keV, spread out at four locations, as the beam will be alternately directed towards four locations on the LEBT chopping aperture. The actual magnitude depends on the effectiveness of the source chopper and may be significantly less than 50 total watts. This power level will be easy to accommodate.

The power density at the MEBT chopper stopper is significantly higher.

If no upstream chopping is carried out, the power dissipated on the MEBT stop is 2.5 MeV $\times$ 28 mA $\times$ 6% $\times$ 35% (off time) = 1.5 kW. Since the source and LEBT choppers are expected to eliminate more than 90% of the average beam power, the average dissipation at the MEBT stop will be less than 150 watts.

However, there will be a full energy 28 mA current spike at the beginning and end of each chopper cycle, about 35-50 nsec long. The beam is focused to a thin ribbon at this point with rms beam sizes of $\sigma_x = 0.18$ cm and $\sigma_y = 0.061$ cm. Assuming a copper absorber (worst case, and also a neutron producer) the range of a 2.5 MeV proton is 0.002 cm, with most of the energy deposited at the Bragg peak. Assume that the volume of energy deposited is $2\sigma_x \times 2\sigma_y \times \frac{1}{2}\text{range} = 4.4 \times 10^{-5}\text{cm}^3$. The instantaneous power density in this volume is 6.3 joules/gram, which is less than than the 500 joules/gram limit for generating a shock wave, as reported by N. Mokhov [FNAL, private communication through C. Celata].

The temperature rise for *one* pulse of 0.0025 joule in this volume is 16.4°K. The thermal relaxation time may be (very crudely) estimated by the following argument. The thermal diffusion rate $P = \partial U/\partial t$ over a temperature difference ΔT is:

$$\frac{\partial U}{\partial t} = k_t \frac{A}{l} \Delta T$$

where A is the area of contact, l the diffusion length and k_t the thermal conduction coefficient. The temperature rise due to a quantity of energy U deposited in volume $V = 2\sigma_x \times 2\sigma_y \times \text{range}/2$ with density d is

$$\Delta T = U \frac{1}{k_h d V}$$

where k_h is the thermal heat capacity of the absorber. The above equations are combined to give the diffusion equation

$$\frac{\partial U}{\partial t} = U \frac{k_t}{k_h} \frac{A}{l d V} = -cU$$

or, for copper and the above geometric values, $1/c$ =the $1/e$ diffusion time of 1.7 microseconds. In a 1.7 microsecond interval, there are approximately four 35 nsec 0.0025 joule bursts, each raising the temperature in the center of the deposited volume of 16.4°K, which would be expected to asymptote out at about twice this value (very crudely).

We can therefore conclude that local heating in the MEBT chopper stopper will probably not be a problem, and that no shock wave will be generated that will destroy the target.

Parameter Summary

	Source	LEBT	MEBT	
Beam Energy	low	0.065	2.5	MeV
Transition Time	100	35-50	<5	nsec
Average Power	NA	<50	<150	watts
Energy/transition	NA	<.5	2.5	mJ
rms spot area		1.3	1.1	mm^2